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ABSTRACT

This publication reports on resources on the Web for the area of math. A quick look is given at innovative sites under the areas of new resources for students, new ways for teachers and students to interact, new ways of presenting math, and new tools for research. Next, advantages and disadvantages are identified for each of the following technologies: HTML pages with GIF images for equations; Adobe Acrobat (PDF); IBM Techexplorer pages; server-side programming (CGI, Perl, Java, ASP scripts, etc.); and HTML and components (Design Science WebEQ, IBM Techexplorer components). Standards for math communication on the Web are then discussed. A list of the standards that Math on the Web developers should be considered with is given, along with the role each standard plays in the HTML Platform. The role of MathML for dynamic math in Web pages and the HTML Platform versus advantages of the proprietary, single-vendor platforms, are discussed. A list of available software packages that have some level of MathML support is given, followed by descriptions of products in the works that support MathML and the HTML Platform. (Contains 32 references.) (AEF)

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Math on the Web: A Status Report

January, 2001

by Robert Miner and Paul Topping

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We plan on updating this report as the world of Math on the Web changes. If you would like us to let you know, visit **http://www.dessci.com/webmath** to add yourself to our Math on the Web mailing list.

View this paper on-line, where the links and references are live, go to **http://www.dessci.com/webmath/status**.

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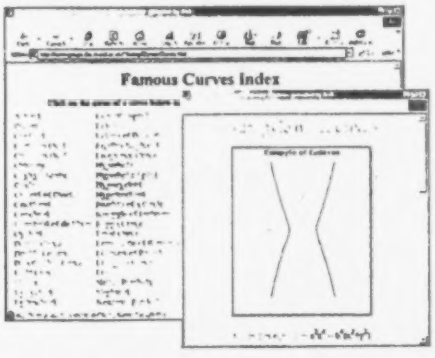
Math on the Web: A Status Report

The Web Revolution

The World Wide Web is nearly a decade old now and its effect on math and science communication has already been amazing. An enormous amount of information has been made available on the Web. Increasingly, cross-referenced research articles and abstracts are available in searchable online archives. In education, engaging interactive materials are widespread, and Web-based course management tools are becoming frequent virtual companions to traditional pedagogical tools. A quick glance at a few innovative sites, many of them long-established, gives an idea of the advances that have been made in the communication of mathematics on the Web:

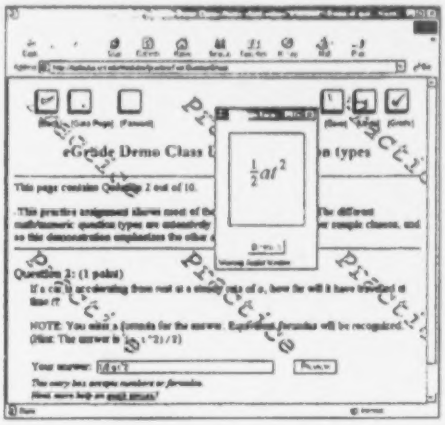
New resources for students

The Math Forum[1] maintains extensive archives of math resources and provides the tremendously popular Ask Dr. Math service where students can get personal answers to questions from a staff of volunteer "math doctors." Math Goodies[2] takes a different approach, offering lessons, puzzles and worksheets with interactive drill problems that give students immediate feedback. The Index of Famous Curves[3] at St. Andrews University represents yet a third kind of resource for students, the multimedia math and science encyclopedia, describing curves with images, equations, and interactive applets.



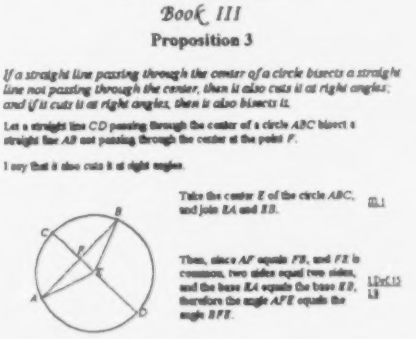
New ways for teachers and students to interact

Many, many course homepages show that teachers are using email, discussion boards, and courseware systems to augment more traditional pedagogical tools. Some commercial courseware systems such as Prometheus[4] offer "complete solutions" including math-enabled tools for posting messages. Other sites offer course management services a la carte, such as the math-capable message board hosting available at LiveMathBoard[5] and math-capable online testing from Wiley e-Grade[6].



New ways of presenting math

The ability to present multimedia information in an interactive way is one of the most enticing aspects of the Web. Many superlative math sites demonstrate how these techniques can be used to make traditional topics come alive, and make advanced topics more accessible. The Knot a Braid of Links[7] has been collecting examples of such sites since 1996, from Euclid's Elements[8] presented via dynamic geometry applets, to simulations of phenomena in wavelet theory such as the Twin Dragon[9].


Euclid's Elements
Book III
Proposition 3
If a straight line passing through the center of a circle bisects a straight line not passing through the center, then it also cuts it at right angles; and if it cuts it at right angles, then it also bisects it.
Let a straight line CD passing through the center of a circle ABC bisect a straight line AB not passing through the center at the point F.
I say that it also cuts it at right angles.
Take the center E of the circle ABC, and join EA and EB.
Then, since AF equals FB, and FE is common, two sides equal two sides, and the base EA equals the base EB, therefore the angle AFE equals the angle BFE.

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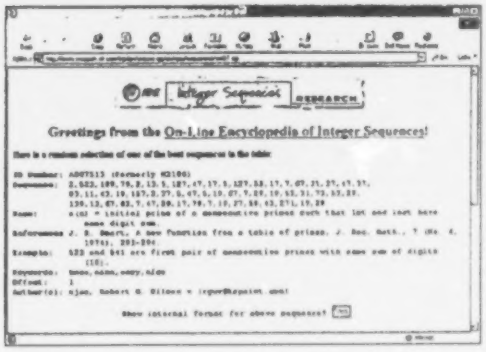
New tools for research

Researchers in academia and industry have also reaped benefits from the Web. Preprint servers such as the arXiv[10] and online journals speed the dissemination of current information, and make articles available for online cross-referencing. Searchable online abstracting services, such as MathSciNet[11], have revolutionized literature searches. And a few innovative sites such as the Sloane's On-Line Encyclopedia of Integer Sequences[12] are beginning to offer specialized searching and indexing on mathematical content, pointing the way toward a future where researchers in widely differing specialties can find connections between each other's work.



Sites such as these demonstrate that the Web can be a powerful vehicle for communicating mathematics and science in general, just as it is revolutionizing communication in other disciplines and fields of endeavor. In spite of this, it is nonetheless true that there are still significant obstacles to publishing mathematics on the Web that other disciplines do not face. As has long been the case in print, authoring and publishing mathematical notation can be a complicated business.

Many Technologies, None Perfect

There are many exciting and innovative math and science Web sites. Their developers are to be applauded, since the technology landscape for Math on the Web is complex. Currently, if you are planning a new Math on the Web project, you must choose from a dazzling array of technologies, each of which has its own advantages and disadvantages.

HTML pages with GIF images for equations:

Advantages

- Because the format is HTML-based, math can more easily be combined with other media such as movies, sounds, interactivity, data access, etc.
- Doesn't require server-side support.
- No need for fonts to be installed (important for cross-platform browsing).

Disadvantages

- Interaction with math is limited to scripts selecting among pre-composed equation images.
- Ugly printing because GIFs are low-res screen images.

Adobe Acrobat (PDF):

Advantages

- Good for online delivery of documents whose primary publishing medium is paper.
- Good quality formatting and printing that is faithful to the designer's original intent.
- Doesn't require server-side support.
- If math fonts are embedded in the document, math symbol display is guaranteed to work.

Disadvantages

- Because the format is not HTML-based, math can't be combined easily with other media such as movies, sounds, interactivity, data access, etc.
- The Web browser is merely hosting the PDF viewer application which must integrate its own user interface with that of the browser. This can be more cumbersome or confusing for the user and limits interaction. Changes made using the browser's interface (e.g. Text Smaller or Larger) have no effect on the PDF display.

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IBM Techexplorer pages (see the comments about Techexplorer components under HTML + Components):

Advantages	Disadvantages
◻ Uses TEX, a language used by legacy documents and understood by many mathematicians. ◻ Doesn't require server-side support. ◻ Prints with TEX quality.	◻ Requires the Techexplorer plug-in which is not free, except for its trial version which doesn't allow documents to be printed. ◻ Although Techexplorer does allow inclusion of basic media formats, math can't be combined with the full range of media available in HTML pages. ◻ The Web browser is merely hosting the viewer application (similar to the PDF Viewer) which must integrate its own user interface with that of the browser. This can confuse the user and limits interaction. Changes made using the browser's interface (e.g. Text Smaller or Larger) have no effect on the display.

Server-side programming (CGI, Perl, Java, ASP scripts, etc.):

Advantages	Disadvantages
◻ Can produce pages as in HTML + Components but avoid the image size problems. ◻ Can produce pages with the widest range of browser compatibility (although this requires some challenging programming). ◻ Minimal load on the client (browser) as all scripts are executed on the server. ◻ Scripting needs only to target the server platform, not all the browser platforms. ◻ Works well for accessing specialized software such as a computer algebra system.	◻ Server-side scripting is difficult to write and debug because (a) it is running on a different computer from the browser, (b) must serve multiple clients simultaneously, (c) it runs the risk of making a production server unstable or requires setting up an identical, parallel server for testing. ◻ Unlike other solutions, all load is concentrated on the server. ◻ User interaction requires a round-trip to the server making interaction sluggish and unpredictable.

HTML + Components (Design Science WebEQ, IBM Techexplorer components):

Advantages	Disadvantages
◻ The page is HTML-based, making it easy to integrate with other Web technologies. ◻ Interaction is snappy as it occurs on the client and doesn't require server-side support. ◻ Interaction is powerful as scripts can generate math to be displayed on the fly.	◻ Interface between math rendering component and page requires that the width and height of each equation be known in advance. This is difficult to do if the math is generated by scripting. ◻ Math pages containing hundreds of individual equations can cause performance problems due to the inability of browsers to handle that many component instances. This issue can be minimized by using components in conjunction with GIFs for non-interactive equations.

Standards are Paving the Way to Better Solutions

Though there are many technologies available for Math on the Web projects, none of them is ideal. Many who consider Math on the Web projects for the first time are surprised that there is no direct support for math in HTML. After all, what is math but fancy text? In fact, this has been proposed and attempts to get it to happen are part of a history almost as long as that of the Web in general.

Efforts to get math into HTML ultimately evolved into the creation of the Math Working Group at the World Wide Web Consortium (W3C), the body responsible for Web standards. The efforts of the Math Working Group ultimately led to the development of MathML, a powerful new language for encoding math expressions for the Web. MathML is now part of an extremely powerful, standardized component-based architecture for the Web, capable of accommodating the requirements of math communication.

The HTML Platform

Each of the many technologies for putting math on the Web has its merits. However, in the long term there can be little doubt that, taken together, the collection of HTML-centric technologies that have taken shape through years of industry collaboration at the W3C represent the future of the Web. We're calling this collection of Web standards the *HTML Platform*.

The problem with current technologies for putting math on the Web is that they are too complicated and ad hoc. It often takes expert knowledge and programming skill to get different math software packages to work together, but no single approach provides a complete answer. The remedy is obviously standards. And although they take time to evolve (through organizations like W3C), once they take hold, their benefits are enormous.

As a consequence, the HTML Platform is the safest bet in the long run for lowest cost of authoring, highest level of capability, reduced vendor lock-in, and the most secure future. To get a better idea of what the HTML Platform consists of, we now take a look at the individual standards of which it is comprised.

For the question, "What language are Web pages written in?", the short answer is, "HTML, of course!". The long answer is, well, longer. Although very simple Web pages can be written in HTML alone, most pages are constructed from a conglomeration of computer languages and mechanisms working together. They go by acronyms like HTML, CSS, XSL, DOM, and MathML. These languages are defined by standards published by the W3C. (They actually call them "recommendations" rather than "standards" but they work the same way.)

Here is a list of the standards that Math on the Web developers should be concerned with, along with the role each plays in The HTML Platform:

Standard	Long Name	Role
HTML[13]	HyperText Markup Language	Defines the document structure and acts as the glue that holds all the other pieces together.
CSS[14]	Cascading Style Sheets	Associates formatting information (font, size, style, color, etc.) with HTML structural elements (headings, paragraphs, tables, etc.).
XML[15]	Extensible Markup Language	The universal format for structured documents and data on the Web. Based on the earlier, more complex, SGML standard. XML is not itself a language but a meta-language used to create other languages, such as XSL, XHTML, MathML, ChemML, etc.
XSL[16]	Extensible Stylesheet Language	Consists of two parts: □ XSL Transformations[17] (XSLT): a language for transforming XML documents □ An XML vocabulary for specifying formatting semantics (XSL Formatting Objects)

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Standard	Long Name	Role
DOM[18]	Document Object Model	The Document Object Model is a platform-and language-neutral interface that will allow programs and scripts to dynamically access and update the content, structure and style of documents.
JavaScript		Simple scripting language used to make Web pages react to user input. Typically, scripts use the DOM to modify the Web page within the browser. All execution occurs on the "client" (Web browser) as opposed to the "server" (Web server).
DHTML	Dynamic HTML	HTML plus the ability to include scripts within a Web page to accept user input, perform computations, and modify the Web page within the browser using the DOM interface in order to effect user feedback.
XHTML[13]	Extensible HTML	An XML-based version of HTML.
MathML[19]	Mathematical Markup Language	An XML-based language for describing mathematics for both presentation and computation.
CML[20] and other MLs	Chemistry Markup Language, etc.	Other domain-specific markup languages may be used in a Web page to describe structured text and/or data.
Applets and Plug-ins		Separately downloadable mini-applications that extend the capabilities of the browser. These may be written in Java for cross-platform compatibility or in C++ for performance. The WebEQ™ Equation Input Control is a good example, providing a way for users to enter math notation and send it to the Web page as MathML.

You can find out more about most of these pieces of the HTML Platform by visiting the W3C's Web site at http://www.w3.org/. Links to specific standards are also listed in References.

All modern Web browser makers have committed to supporting the standards of the HTML Platform. For the Math on the Web author, it is largely a matter of when, not if, a browser implements a particular HTML Platform standard. Like all new technology, the HTML Platform is not standing still. The W3C and its member organizations are constantly pushing the HTML Platform forward. Although the Math on the Web author must still be concerned with questions about whether *this* technology is supported in *that* browser, this is inevitably the case with leading-edge technologies.

The role of MathML in a dynamic math page

MathML support is already widespread enough that it has begun to play a pivotal role for *dynamic math* in Web pages. Part of the appeal of the Web as a medium is that it is interactive. Information is presented in an active environment with many kinds of interactive controls. In the case of math content, MathML-capable components can be "wired together" to create dynamic math and science pages.

The most basic situation are MathML "islands" in the Web page, which display as traditional mathematical notation. In some browsers like Amaya and Mozilla, display of MathML islands is now built-in. With Netscape and Internet Explorer, MathML can be rendered via plug-ins or applets.

The role of MathML islands in an HTML document is similar to the role of TEX's math mode within a TEX document. However, MathML has the potential to go much farther than TEX's static math. MathML equations can be manipulated using JavaScript, and styled using CSS. Equations can be hooked up to HTML controls like buttons and pulldown menus. Applets and plug-ins can send MathML-encoded equations to server-side software such as computer algebra systems or scientific visualization software.

The combination of MathML and scripting facilitate an enormous range of dynamic math applications. Here are some possibilities:

- When the user clicks on a button in the page, a script is invoked that modifies a MathML island using DOM access. The user sees the math change based on the click. A typical use might be to display a hint to a student in a lesson.
- An interactive assessment page allows the student to invoke an equation editor applet. When the user closes the editor window, the MathML for the equation is sent as input to a script that sends it back to the Web server. Software on the Web server checks the student's answer and sends the result back to the script running in the page which informs the user of his/her success/failure.
- A Web page that works as a special-purpose calculator and grapher allows the user to make radiobuttor and checkbox choices and enter numerical coefficients. A script invoked by a "Compute" button generates MathML that will be sent to a Computer Algebra System or other computational component running on the client or server computer. The results are shown to the user both as a graph (using a graphing applet) and in standard mathematical notation.

Much as HTML is the glue that binds the various parts of the Web page together, MathML is the glue that binds the mathematical and computational elements together. MathML is the language with which the equation editor applet, the Computer Algebra System, and the graphing applet communicate.

The HTML Platform vs. proprietary, single-vendor platforms

The biggest choice facing the Math on the Web author is whether to go with a proprietary, single-vendor platform, or to stick with a open standards-based, multi-vendor platform. The standards-based platform is the better choice in the long run, but the case isn't so clear when you have to do something today. This is a very common dilemma for technology adopters. The proprietary, single-vendor solution has some advantages, especially in the short term:

- Available sooner;
- Easier to evaluate for possible adoption;
- Once adopted, easier to learn as there is a single source for all documentation, knowledge, and support.

The proprietary, single-vendor solution has some big disadvantages which grow as time passes:

- The vendor is slow to implement new technologies as it has to do all the work itself.
- The customer gets locked in to the proprietary solution as there are no alternate vendors.
- Switching to the open standards-based, multi-vendor solution can be difficult and costly as the customer has a huge investment in training, expertise, and experience in dealing with the single vendor's system, much of which may have to be discarded.
- It is usually more difficult for a proprietary system to interoperate with standards-based systems. This is what occurs when Adobe Acrobat, IBM Techexplorer, and other viewers take over the browser. The viewer's user interface must be overlaid on top of the browser's, thereby confusing the user.
- The proprietary vendor can charge higher prices, especially after the initial purchase (e.g. support, upgrades, etc.) because of the customer's difficulty in switching vendors.

In the long term, the open standards-based, multi-vendor solution has big advantages that grow even larger as time passes:

- Multiple, competing vendors for each component of the solution (authoring systems, in-page editors, applets, browsers, etc.) mean more customer choice of product and vendor, lower prices, more features. This is capitalism at its finest.
- There is much less vendor lock-in. Switching vendors is easier for a single part of your solution than for the whole thing.
- It will be easier to find training, support, contract help, etc. as the technologies you are dealing with will be mainstream, often not specific to Math on the Web.
- Similarly, trained and experienced personnel will be easier to find and train as the skills you will be looking for will be common.

What's Available Now

There are already a number of software packages that have some level of MathML support. In particular, Design Science is one of the oldest and most respected vendors of MathML software. Our WebEQ software was the first commercially available software with MathML support, MathType™ was the second.

The following list touches on some of the highlights:

From Design Science (DSI)[31]:

- MathType — DSI's premiere equation editor can export equations as MathML. MathType gives an easy way of authoring MathML expressions.
- WebEQ Math Viewer — this scriptable Java applet displays math expressions in Web pages, and can dynamically update the display in response to mouse gestures or other controls, such as buttons, in a Web page.
- WebEQ Equation Input Control — The Equation Input Control (or EIC) is a Java equation editor applet. The EIC gives readers a way to enter math on a Web page, in addition to the other standard HTML input controls like text areas and radio buttons. The EIC is configurable to meet a range of authoring needs.

From the TEX Community[32]:

- tex4ht[33] — this free Perl program is a very powerful HTML translator, generating HTML + MathML from LATEX.
- PassiveTEX[34] and xmltex[35] — these free macro packages facilitate using TEX to directly typeset MathML.

From Wolfram Research[36]:

- Mathematica 4.x — this powerful scientific computation platform can import, export, and evaluate MathML.

From IBM:

- IBM Techexplorer[37] — the IBM Techexplorer plug-in takes over the browser window to display TEX documents by default. However, with some effort, Techexplorer can also be used as a component within the HTML platform to display and manipulate MathML expressions in a way similar to the WebEQ Math Viewer.

Browsers:

- Amaya[38] — the demonstration and test-bed browser from W3C supports both display and editing of MathML.
- Mozilla[39] — the open source version of the Netscape browser currently implements most of MathML. There is a strong likelihood MathML support will appear in the Netscape-branded version of the browser before long.
- Internet Explorer[30] — Microsoft has introduced a new plug-in technology called "Behaviors"[31] that allows much better integration into a Web page than other plug-in technologies. More on this below.

For a more comprehensive list of MathML-enabled software, consult the W3C Math home page.

What's in the Works

Design Science[31] will be introducing a number of products supporting MathML and the HTML Platform in early 2001:

MathPlayer

- MathPlayer™ is a state-of-the-art plug-in that enables Internet Explorer (IE) to display MathML. Developed in collaboration with Microsoft using IE's Behavior technology, MathPlayer seamlessly integrates MathML into Web pages, automatically matching font sizes and styles, flowing and aligning with surrounding text, and printing at high-quality. MathPlayer is designed to be part of the HTML Platform, and can be scripted with JavaScript, and styled with CSS.

  MathPlayer will be available free-of-charge.

MathType 5 with MathPage technology

- The next version of Design Science's premiere MathType equation editor will revolutionize the process of exporting a Word document with math

to the Web. DSI's MathPage™ technology augments Word's "Save As HTML" feature in powerful ways.

MathPage uses the full power of the HTML platform to create HTML pages with math as MathML islands for display in MathML-capable browsers, such as IE with MathPlayer, Mozilla, and Amaya. For maximum backward compatibility, MathPage can also produce math as GIF images, with high resolution images for printing, all perfectly aligned with the surrounding text.

WebEQ 3

- WebEQ, the oldest and most comprehensive set of tools for building dynamic math Web sites, is getting a load of exciting new features in its next release. The core WebEQ MathML engine has been completely updated for MathML 2 and features better rendering, more intuitive editing, and automatic line breaking. WebEQ 3 will also introduce direct authoring of *content MathML* which encodes both how an equation should evaluate and how it should look.

  The WebEQ Math Viewer and Equation Input Control will both offer many new scripting and configuration options, and the WebEQ MathML Editor and Page Wizard programs will provide Web developers with the most powerful tools available for directly authoring and processing MathML.

Conclusion

A great math site is great because of its content, not its technology, and that will never change. But the technology is important too, and the many choices between solutions, none of which are ideal, have posed a real obstacle to would-be Web authors and readers. Standards have been developed at the W3C to address the problems, and the HTML Platform that has emerged from these efforts is a very powerful and flexible architecture for math and science publishing on the Web. But as always, for authors making choices today, the paramount question is "What works now, and when's the next release?"

On that point, the current picture is quite positive. As we have seen, MathML is becoming widely supported. The First International MathML Conference[32] was held this fall, and the amount and quality of MathML implementation work on display was impressive. By the end of next year, excellent MathML support will be freely available in most major browsers. Several computer algebra systems currently support MathML, and more are on the way. Excellent authoring tools are available for developers. And much, much more is on the way, from Design Science and others.

Math on the Web has come a long way, and has a bright future. Design Science believes the coming year is going to be a very big one for Math on the Web. The HTML Platform has matured over the last two years, and Math on the Web is well on the way toward claiming the benefits.

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